Cementless unicompartmental knee replacement achieves better ten year clinical outcomes than Cemented – A systematic review

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ABSTRACT

Purpose: The aim of this study was to report and compare the long term revision rate, revision indications and patient reported outcome measures of cemented and cementless Unicompartmental knee replacements (UKR).

Methods: Databases Medline, Embase and Cochrane Central of Controlled Trials were searched to identify all UKR studies reporting the ≥10 year clinical outcomes. Revision rates per 100 component years (% per annum (%pa)) were calculated by fixation type and then subgroup analysis for fixed and mobile bearing UKRs was performed. Mechanisms of failure and patient reported outcome measures are reported.

Results: 25 studies were eligible for inclusion (n=10,736), of which there were 8790 cemented and 1946 cementless UKRs. The revision rate was 0.73%pa (CI 0.66-0.80) and 0.45%pa (CI 0.34-0.58) per 100 component years respectively with the cementless having a significantly ($p<0.001$) lower overall revision rate. Therefore, based on these studies, the expected 10 year survival of cementless UKR would be 95.5% and cemented 92.7%. Subgroup analysis revealed this difference remained significant for the Oxford UKR (0.37%pa vs 0.77%pa, $p<0.001$), but for non-Oxford UKRs, there were no significant differences in revision rates of cemented and cementless UKRs (0.57%pa vs 0.69% pa, $p=0.41$). Mobile bearing UKRs had significantly lower revision rates than fixed bearing UKRs in cementless ($p=0.001$), but not cemented groups ($p=0.13$). Overall the revision rates for aseptic loosening and disease progression were significantly lower ($p=0.02$ and $p=0.009$ respectively) in the cementless group compared to the cemented group (0.06 vs 0.13%pa and 0.10 vs 0.21%pa respectively).

Conclusions: Cementless fixation had reduced long term revision rates compared to cemented for the Oxford UKR. For the non-Oxford UKRs the revision rates of cementless and cemented fixation types were equivalent. Therefore cementless UKRs offer at least equivalent if not lower revision rates compared to cemented UKRs.

Key words: Arthroplasty, UKA, Unicondylar

Word count: 293 words

Level of evidence: III

INTRODUCTION

Unicompartmental knee replacement (UKR) is an effective well established treatment for anteromedial knee osteoarthritis which has failed to respond to conservative management [66]. Whilst UKR offers substantial benefits over total knee replacement (TKR) [36, 44, 67] it has a higher revision rate, particularly for aseptic loosening [7, 48, 62].

The two main types of fixation used to implant components are cemented and cementless techniques. Cemented components rely on bone cement to fix the components to surrounding trabecular bone whereas cementless components rely on the principle of press fit fixation and osseointegration [39, 40, 63]. The current gold standard for knee replacements is cemented fixation [7, 48, 62] given the poor results of the first cementless knee replacements [5, 10].

There has been a recent increase in interest in cementless fixation given the need for fixation to last a patient's lifetime with rising life expectancies [32]. Additionally the merits of a more natural biological fixation, avoidance of cementation errors, a reduction in radiolucent lines and pain are certainly attractive [10, 27, 44].

There is currently no consensus of how the overall long term clinical outcomes of cemented UKRs compare to cementless UKRs across the world and for different UKR types. Such a comparison would need to investigate not only the revision rate, but the functional outcomes achieved from both fixation types. This systematic review addresses this question by comparing cemented and cementless UKRs results published globally by comparing; revision rates, revision indications and PROMs. The null hypothesis was that there would be no differences in the revision rates of cemented and cementless UKRs.

MATERIALS AND METHODS

This systematic review has been registered prospectively on PROSPERO, CRD42019134315 and follows the preferred reporting items for systematic reviews (PRISMA).

<u>Inclusion and exclusion criteria</u>

The inclusion criteria were studies in the English language that reported the ≥ 10 year outcomes of any primary medial UKR for osteoarthritis in adult patients. Studies included were from 2009 onwards to assess the outcomes of UKRs published within the last 10 years. This is given that the most commonly used cementless UKRs were introduced after cemented versions and first broadly used around 2009 onwards [42]. Additionally using studies before this period would include a disproportionate number of older cemented UKR studies which would not be deemed as comparable to the more recent cementless UKR studies.

Exclusion criteria included registry studies given they tend not to subdivide implants according to fixation and whether the implant is medial/lateral and to prevent duplication of patients with existing studies in the literature [7, 48]. Additionally registries can under report revisions [57]. Additional exclusion criteria were case reports, abstracts, hybrid UKRs and any studies in which lateral UKRs formed more than 10% of the whole cohort given our study was focusing on medial UKR outcomes. Studies of all polyethelene tibial components, bicompartmental replacements and those looking at only certain subgroups of the population were excluded given these contribute potential unnecessary confounders. Details of the number of articles actually excluded from the study based on the inclusion and exclusion criteria specified are summarised in Figure 1.

Search strategy

Alongside an expert librarian, the databases Medline, Embase, Central were searched from their inceptions to 23/04/2019 and are summarised in the Appendix. Key words used in the search strategy included "knee arthroplasty" and "fixation" with all variations of these terms. In addition reference lists of the included publications were also screened to identify any additional reports.

First study duplicates were removed followed by a title and abstract screening based on eligibility criteria. All shortlisted papers had full texts extracted and were assessed. Where the same cohort was published more than once, the most recent publication using the full cohort was included. There was complete agreement between the independent authors (HRM, GB) who screened the studies.

Outcomes of interest

The primary outcome of interest was revision. This was measured from ; (1) revision rate and (2) 10 year survivals reported. Revision was defined as any removal/addition of any component to the knee joint as per the registries [7, 48, 62]. Secondary outcomes were (1) Revision indications and (2) PROMs.

The a priori analysis was to first compare fixation groups (cementless vs cemented), and then compare bearing type (mobile vs fixed bearing) results within each fixation category.

Data collection and risk of bias

Two authors (HRM and GB) independently extracted data from all included studies. Contact attempts were made for all authors to obtain missing information. In cases where a study reported results for both cemented and cementless fixation types, only UKR arms reporting long term outcomes were included in the review as per the specified inclusion criteria.

All studies were assessed for risk of bias using the methodological index for evaluation of non-randomised studies (MINORs) as a percentage and an additional system based on the reporting of the primary outcome (A=clearly reported, B=not reported/unclear) and the number of cases (A > 100 cases, B 51-99 and C <50) [10, 15, 44, 60]. Studies with a MINORs score over 80% were deemed at low risk of bias and those below 70% at high risk except those with three or more As in the primary outcomes [10, 15, 44, 60].

Data synthesis and analysis

The primary outcome, the revision rate was calculated per 100 component years which is equivalent to the annual rate (% per annum (%pa)) as per the Australian Joint Registry [7] and previous reports [10, 25, 33, 44]. This involved dividing the total number of revisions by the total observed component years multiplied by 100 [50]. 95% confidence intervals (CI) were generated using the Clopper Pearson method [14]. Each revision indication rate was also calculated using the same methodology. Revisions and their indications per 100 component years were compared between groups using the chi squared proportional test.

From the included studies Campi et al. (2018A) [11] reported the results for 1000 UKRs, but of these, 318 UKRs were also used in Mohammad et al's. [41] more recent study. The results of Campi et al's. (2018A) [11] unique 682 UKRs were obtained to prevent duplication of UKRs in the analysis. Therefore in this systematic review the number of UKRs reported for Campi et al. (2018A) [11] is 682. This prevented overpowering the study and used the most up to date information for the cohort.

All statistical analysis was performed using Stata. P values of <0.05 were deemed statistically significant.

RESULTS

5,835 articles were identified, which after duplicates and title/abstract screening were reduced to 39. Full text analyses deemed 25 articles eligible for inclusion (Figure 1). Details of full text articles excluded are in Table 1. There were 21 studies [3, 4, 6, 12, 13, 16-19, 29, 31, 37, 38, 51, 55, 59, 61, 64, 65, 68, 69] reporting the long term outcomes of cemented UKRs and 5 [11, 20, 34, 41, 59] reporting the outcomes of cementless UKRs. The majority of studies (15/25) were of the Oxford UKR (Table 2). All identified studies were observational studies with no long term comparative studies. All studies scored low risk of bias except Aly et al. [4] (Table 3). The total number of UKRs in the cemented and cementless groups were 8,790 and 1,946.

Revisions by fixation type

24 out of 25 studies (n=10,054) reported the number of revisions during the study period and the mean follow up which allowed for quantitative analysis (Figure 2). The only exception to this was Price et al. (n=682) [55] which reported the median follow up. Table A1 in the appendix summarises this in detail for each study.

The overall revision rate for the cemented and cementless groups were calculated separately. In the cemented group (n=8,108) there were 456 revisions out of 62,637 component years resulting in a revision rate of 0.73%pa (CI 0.66-0.80) (Table A1). This equates to a 10 year survival of 92.7%. In the cementless group (n=1946) there were 57 revisions out of 12,740 component years resulting in a revision rate of 0.45%pa (CI 0.34-0.58) (Table A1). This equates to a 10 year implant survival of 95.5%. The differences between cementless and cemented revision rates were significant ($p<0.001$). The revision rates are plotted in Figure 2.

There were 13 studies of the cemented Oxford UKR (n=6,326) and 2 studies of the cementless Oxford UKR (n=1,682). For the cemented Oxford, there were 381 revisions out of 49,384 component years giving a revision rate of 0.77%pa (CI 0.70-0.85). The cementless Oxford studies reported 37 revisions out of 9,874 component years giving a revision rate of 0.37%pa (CI 0.26-0.52). The difference between the revision rates was significant ($p<0.001$).

There were 10 studies of non-Oxford UKRs, of which 8 had cemented UKRs (n=1,782) and 3 had cementless UKRs (n=264). For the cemented UKRs, there were 75 revisions out of 13,253 component years giving a revision rate of 0.57%pa (CI 0.45-0.71). For the cementless UKRs, there were 20 revisions from 2,866 component years giving a revision rate of 0.69%pa (CI 0.43-1.10). There were no significant differences in the cemented and cementless non Oxford UKR study's revision rates (p=0.41).

Revisions by bearing type

In the cemented group (n=8,108) there were 6,478 mobile bearing UKRs [3, 4, 12, 16-18, 29, 31, 38, 51, 59, 65, 69] and 1,071 fixed bearing UKRs [6, 19, 37, 61, 64, 68] clearly indicated. Chatellard et al. [13] (n=559) had a mixture of mobile and fixed bearing UKRs and hence was not included in this analysis. There were 388 revisions out of 50,934 component years and 54 revisions out of 8,813 component years for mobile and fixed bearing cemented UKRs respectively. This resulted in revision rates of 0.76%pa (CI 0.69-0.84) and 0.61%pa (CI 0.46-0.80) respectively (Figure 3, Table A1). The corresponding 10 year implant survival for mobile and fixed cemented UKRs were 92.4% and 93.9%. The differences in revision rates between mobile and fixed bearing cemented UKRs were not significant (p=0.13).

In the cementless group (n=1,946) there were 1,760 mobile bearing UKRs [11, 41, 59] and 186 fixed bearing UKRs [20, 34]. There were 39 revisions out of 10,779 component years and 18 revisions out of 1,961 component years. This resulted in revision rates of 0.36%pa (CI 0.26-0.50) and 0.92%pa (CI 0.54-1.45) respectively (Figure 3, Table A1). The 10 year survival for mobile and fixed bearing cementless UKRs were 96.4% and 90.8% with this difference being significant (p=0.001).

Implant survival reported

Of the 21 cemented studies, 19 studies reported the long term survival. 15 studies reported the implant survivals at 10 years and ranged between 83.7 to 96.3% (Table 4). All 5 cementless studies reported long term implant survivals. 3 studies reported the 10 year implant survival ranging between 96.6 to 97.5% (Table 4).

Indications for revision

All studies (23 studies, n=9,532; 7,586 cemented and 1,946 cementless)) except Campi et al. (2018B) [12] and Price et al. [55], reported the mechanisms of failure by fixation type and mean follow up time (Table A2). The revision rates per 100 component years for aseptic loosening and disease progression were significantly lower (p=0.02 and p=0.009 respectively) in the cementless group compared to the cemented group (0.06 vs 0.13%pa and 0.10 vs 0.21%pa respectively). The revision rate for polyethylene wear/impingement was significantly higher (p=0.03) in the cementless group (0.05 vs 0.02%pa). No other revision indication was significantly different between cementless and cemented UKRs (Table 5).

Patient reported outcome measures

13/21 cemented studies and 4/5 cementless studies reported the long term PROMS for the overall cohort studied. Studies reporting preoperative PROMs all showed an improvement at the ≥ 10 year scores. For the cemented UKRs the 10 year OKS reported ranged between 37 to 41.9 and for the cementless it ranged from 38 to 41.7 (Table 6).

DISCUSSION

This is the first systematic review to the best of the author's knowledge comparing the long term outcomes of cemented and cementless UKRs. Overall cementless UKRs had a revision rate that about one third lower than cemented. This difference appears to be due to the rates of revision for aseptic loosening more than halving.

Although historically cementless implants had a reputation of poor outcomes [10], this review suggests that they currently achieve similar if not better results than cemented implants. This review's results are in agreement with a recent registry based propensity matched comparison of cemented and cementless Oxford UKRs [42], which found that the revision rate of the cementless was nearly a third less than the cemented and the revision rate for aseptic loosening more than halved. There are also concerns that cementless fixation is less forgiving than cemented and that only high volume surgeons would benefit. However another study has found the merits of cementless are independent of surgeon volume [43]. Therefore all surgeons should at least consider using cementless UKR implants.

The fact that cementless UKRs had significantly lower revision rates only for the Oxford UKRs could be because of the limited numbers in the non-Oxford implant group making it more prone to type 2 error. However despite this, the revision rates of the non-Oxford UKR fixation groups were essentially equivalent. The other possibility is the design of the Oxford UKR, which is ligament preserving with a mobile bearing resulting in predominantly compressive loads with minimal shear, is ideal for cementless fixation.

Randomised studies comparing UKR fixation showed a significant reduction of radiolucencies in cementless groups indicative of improved fixation [27, 52]. This probably explains why the rates of revision for loosening reduced. The decrease in revision rate for arthritis progression with cementless fixation is more difficult to explain. Possible explanations include cement fragments causing direct damage to the lateral compartment or cementing errors causing medial overstuffing resulting in lateral overload. The cementless Oxford UKR femoral component, compared to the cemented, has an additional anterior peg to improve fixation. To accommodate this more bone has to be removed anterior to the femoral component which may decrease the risk of the bone impinging on the bearing, which is known to increase the risk of disease progression [56]. Additionally the overall mean follow up, weighted on each studies sample size differed between fixation groups (Cemented=7.7yrs, Cementless=6.5yrs). Arthritis progression tends to occur late, so the longer weighted mean follow-up in the cemented group will disproportionately increase its revision rate specifically for this indication. Conversely the anterior extension on the cementless component might explain the increased rate of revision for this reason.

No obvious differences in long term PROMs were found between the cementless and cemented groups. However both groups had better PROM scores than those commonly reported for TKR [46].

There are two fundamentally different design concepts for UKR; mobile and fixed bearings. The debate of which is better has been a contentious issue [49]. Theoretical advantages of a mobile bearing UKR include lower linear polyethylene wear, better long term knee kinematics, and a more even load distribution at the implant-bone interface [35]. However fixed bearings have the advantages of not dislocating. Our study showed that mobile bearing UKRs had significantly lower revision rates than fixed bearing UKRs in the cementless but not cemented groups. Other reviews and clinical studies, which were predominantly based on cemented components also found no differences in their outcomes [35, 45, 54].

The main limitation of this review is that all included studies were observational cohorts with no comparative control arm. Although there has been a formal comparison of the overall revision rates of cemented and cementless UKR from studies using the proportional chi squared test, this must be interpreted with caution given this is an overall comparison between studies and not from a pooled comparison within studies. Therefore it does not account for confounding factors, or selection bias related to the selection of patients included in these cohorts with different lengths of follow up. There is considerable heterogeneity between studies (Figure 2) where the revision rate can be seen to vary between studies, particularly for the cemented studies. Additionally given the cementless studies are understandably from fewer centres this may introduce a possible expertise bias. However it is encouraging that our results mirror those published from propensity matched registry comparisons, which address these limitations [42]. Larger UKR numbers would cause the revision rate to fall, but this would not explain the lower revision rates in the cementless group as they had far fewer UKRs than the cemented group. Finally the study was limited given most studies were of the Oxford UKR but this reflects the current literature and highlights the need for more long term non-Oxford UKR studies of both fixation types.

CONCLUSIONS

Cementless fixation offers lower long term revision rates compared to cemented, particularly in mobile bearing UKR, with a reduction in aseptic loosening rates suggesting improved fixation. All surgeons should therefore at least consider using cementless UKRs in their practice.

FIGURE LEGENDS

Figure 1. PRISMA flow chart

Figure 2. Forest plot of revision rates per 100 component years of cemented and cementless UKR studies

Figure 3. Forest plot of revision rate per 100 component years by fixation and bearing type

LIST OF TABLES

Study	Reason for exclusion
Abdulkarim et al. 2013 [1]	Abstract only
Ali et al. 2015 [2]	Same cohort as Pandit et al 2015 [51] but earlier results
Bottomley et al. 2016 [8]	Does not report results of cemented or cementless UKRs separately
Bray et al. 2017 [9]	Abstract only
Campi et al. (2018B) [12] (cementless arm)	Cementless arm only reports short to midterm follow up. Cemented arm included in the review as reports long term outcomes.
Hamilton et al. 2016 [24]	Same cohort as Pandit et al 2015 [51] and only analyses subgroup of the cohort.
Hamilton et al. 2017 [23]	Same cohort as Pandit et al 2015 [51] and only analyses subgroup of the cohort.
Hamilton et al. 2017 [22]	Same cohort as Pandit et al 2015 [51] and only analyses subgroup of the cohort.
Hamilton et al. 2017 [21]	Same cohort as Pandit et al 2015 [51] and only analyses subgroup of the cohort.
Heyse et al. 2012 [26]	Only analyses patients under 60 years of age
Kennedy et al. 2018 [28]	Same cohort as Pandit et al 2015 [51] and only analyses subgroups of the cohort.
Kim et al. 2017 [30]	Only analyses patients under 60 years of age
Noaur et al. 2016 [47]	Not available in English language and also only analyses patients under 60 years of age
Parratte et al. 2009 [53]	Only analyses patients under 50 years of age
Saragaglia et al. 2018 [58]	Exclude as over 10% of cohort are lateral UKRs

Table 1. List of excluded full texts and reasons

	UKR prosthesis	Number of UKRs	Number of surgical centres
Cementless UKR studies			
Campi et al. (2018A) [11]	Oxford	682	2
Hall et al. (2013) [20]	Unix	85	1
Lecuire et al. (2014) [34]	Alpina	101	1
Mohammad et al. (2019) [41]	Oxford	1000	1
Schlueter-Brust et al. (2014) [59] (cementless arm)	Uniglide	78	1
		Total: 1,946	**Total: 6**
Cemented UKR studies			
Alnachoukati et al. (2018) [3]	Oxford	825	4
Aly et al. (2010) [4]	Oxford	45	1
Argenson et al. (2013) [6]	Miller-Galante	70	1
Campi et al. (2018B) [12] (cemented arm)	Oxford	522	1
Chattelard et al. (2013) [13]	Alegretto, Presevation, Genesis, Hermes, HLS, Lotus, Miller-Galante, Oxford	559	13
Edmonson et al. (2015) [16]	Oxford	364	1
Emerson et al. (2016) [17]	Oxford	213	1
Faour Martin et al. (2013) [18]	Oxford	511	1
Foran et al. (2013) [19]	Miller-Galante	19	1
Kim et al. (2015) [29]	Oxford	180	1
Kristensen et al. (2013) [31]	Oxford	695	1
Lim et al. (2018) [37]	Miller Gallante/Preservation UKR	279	1
Lisowiski et al. (2016) [38]	Oxford	138	1
Pandit et al. (2015) [51]	Oxford	1000	1
Price et al. (2011) [55]	Oxford	682	1
Schlueter-Brust et al. (2014) [59] (cemented arm)	Uniglide	152	1
Song et al. (2016) [61]	Miller-Galante	68	1
Venkatesh et al. (2016) [64]	Miller-Galante	175	1
White et al. (2018) [65]	Oxford	554	2
Winnock de Grave et al. (2018) [68]	Zimmer Unicondylar Knee	460	1
Yoshida et al. (2013) [69]	Oxford	1279	2
		Total: 8,790	**Total: 38**

Table 2. Breakdown of UKR prostheses used in included studies

Study	MINORS %	Sample size	Revisions reported	Implant survival reported	Mechanisms of failure reported	Bias risk
Cementless UKR studies						
Campi et al. (2018A) [11]	75	A	A	A	A	Low
Hall et al. (2013) [20]	75	B	A	A	A	Low
Lecuire et al. (2014) [34]	75	A	A	A	A	Low
Mohammad et al. (2019) [41]	87.5	A	A	A	A	Low
Schlueter-Brust et al. (2014) [59]	87.5	A	A	A	A	Low
Cemented UKR studies						
Alnachoukati et al. (2018) [3]	87.5	A	A	A	A	Low
Aly et al. (2010) [4]	56.3	C	A	B	A	High
Argenson et al. (2013) [6]	87.5	A	A	A	A	Low
Campi et al. (2018B) [12]	87.5	A	A	A	A	Low
Chattelard et al. (2013) [13]	62.5	A	A	B	A	Low
Edmonson et al. (2015) [16]	68.8	A	A	A	A	Low
Emerson et al. (2016) [17]	75	A	A	A	A	Low
Faour Martin et al. (2013) [18]	87.5	A	A	A	A	Low
Foran et al. (2013) [19]	75	B	A	A	A	Low
Kim et al. (2015) [29]	75	A	A	A	A	Low
Kristensen et al. (2013) [31]	81.3	A	A	A	A	Low
Lim et al. (2018) [37]	87.5	A	A	A	A	Low
Lisowiski et al. (2016) [38]	81.3	A	A	A	A	Low
Pandit et al. (2015) [51]	81.3	A	A	A	A	Low
Price et al. (2011) [55]	87.5	A	A	A	A	Low
Schlueter-Brust et al. (2014) [59]	87.5	A	A	A	A	Low
Song et al. (2016) [61]	87.5	B	A	A	A	Low
Venkatesh et al. (2016) [64]	81.3	A	A	A	A	Low
White et al. (2018) [65]	87.5	A	A	A	A	Low
Winnock de Grave et al. (2018) [68]	81.3	A	A	A	A	Low
Yoshida et al. (2013) [69]	81.3	A	A	A	A	Low

Table 3. Risk of bias of cemented and cementless UKR studies.

Study	Implant survival reported	Time point
Cementless UKR		
Campi et al. (2018A) [11]	96.6%	10 years
Hall et al. (2013) [20]	76.0% (CI 60.0-97.0)	12 years
Lecuire et al. (2014) [34]	88.0% (CI 81.0-95.0)	13 years
Mohammad et al. (2019) [41]	97.5% (CI 95.7-98.5)	10 years
Schlueter-Brust et al. (2014) [59] (cementless arm)	97.4%	10 years
Cemented UKR		
Alnachoukati et al. (2018) [3]	85.0 (CI 81.2-88.8)	10 years
Aly et al. (2010) [4]	n.r	10 years
Argenson et al. (2013) [6]	94.0 (CI 91.0-97.0)	10 years
Campi et al. (2018B) [12] (cemented arm)	n.r	10 years
Chattelard et al. (2013) [13]	83.7 (CI 80.2-87.2)	10 years
Edmonson et al. (2015) [16]	87.9 (CI 82.5-93.3)	11 years
Emerson et al. (2016) [17]	88.0 (CI 82.4-93.6)	10 years
Faour Martin et al. (2013) [18]	96.3	10 years
Foran et al. (2013) [19]	93.0 (CI 83.0-98.0)	15 years
Kim et al. (2015) [29]	90.5 (CI 85.9-95.0)	10 years
Kristensen et al. (2013) [31]	85.3 (CI 78.7-90.0)	10.7 years
Lim et al. (2018) [37]	95.1 (CI 92.2-97.7)	10 years
Lisowiski et al. (2016) [38]	90.6 (CI 85.2-96.0)	15 years
Pandit et al. (2015) [51]	96.0 (CI 92.5-99.5)	10 years
Price et al. (2011) [55]	93.6 (CI 90.6-96.6)	10 years
Schlueter-Brust et al. (2014) [59] (cemented arm)	95.4	10 years
Song et al. (2016) [61]	95.6	10 years
White et al. (2018) [65]	95.2 (CI 92.3-98.4)	12 years
Winnock de Grave et al. (2018) [68]	94.2 (CI 86.8-97.5)	10 years
Venkatesh et al. (2016) [64]	96.0	10.9 years
Yoshida et al. (2013) [69]	95.4 (CI 91.2-99.7)	10 years

Table 4. Long term implant survivals for the overall cohort from each of the included studies

Indication for revision	No of cemented cases (n=7,586)	Percentage of cemented cases	Revisions per 100 component years for each indication (% pa)	No of cementless cases (n=1,946)	Percentage of cementless cases	Revisions per 100 component years for each indication (%pa)	Comparison between groups P value
Disease progression*	125	1.6%	0.21	13	0.7%	0.10	P=0.009
Aseptic loosening*	76	1.0%	0.13	7	0.4%	0.06	P=0.02
Bearing dislocation	41	0.5%	0.07	15	0.8%	0.12	P=0.08
Pain	50	0.7%	0.09	5	0.3%	0.04	P=0.09
Infection	34	0.4%	0.06	3	0.2%	0.02	P=0.14
Other	15	0.2%	0.03	3	0.2%	0.02	P=1.0
Unknown	16	0.2%	0.03	0	0%	0	P=0.09
Instability	17	0.2%	0.03	0	0%	0	P=0.06
Polyethelene wear/fracture*	12	0.2%	0.02	7	0.4%	0.05	P=0.03
Periprosthetic fracture	10	0.1%	0.02	3	0.2%	0.02	P=0.72
Hemarthrosis	6	0.1%	0.01	0	0%	0	P=0.60
Malposition	16	0.2%	0.03	1	0.1%	0.008	P=0.34

Table 5. Indications for revision surgery in the cemented and cementless cohorts. The Chi squared proportions test was utilised to compare each revision indication per 100 component years except when the expected frequency <5 where the fisher exact test was utilised. * Indicates revision indications significantly different between groups.

Study	Patient reported outcome measure	Time point
Cementless UKR		
Campi et al. (2018A) [11]	OKS 41.7 (SD 6.8)	10 years
Hall et al. (2013) [20]	OKS 38 (range 13-48), WOMAC 20 (range 0-72)	10 years
Lecuire et al. (2014) [34]	AKSS 171.4 (SD 25.3)	10 years
Mohammad et al. (2019) [41]	OKS 41.2 (SD 9.8), Tegner 2.8 (SD 1.3), AKSS-0 89.1 (SD 13.0), AKSS-F 80.4 (SD 14.6)	10 years
Schlueter-Brust et al. (2014) [59] (cementless arm)	n.r	n.r
Cemented UKR		
Alnachoukati et al. (2018) [3]	AKSS-F 77 (SD 28), AKSS-O 90 (SD 18)	10 years
Aly et al. (2010) [4]	HSS 177.6 (range 78-198)	10 years
Argenson et al. (2013) [6]	KSS Clinical 91 (range 50-100) KSS Functional 88 (range 45-100)	20 years
Campi et al. (2018B) [12] (cemented arm)	n.r	n.r
Chattelard et al. (2013) [13]	n.r	n.r
Edmonson et al. (2015) [16]	AKSS-O 87, AKSS-F 73, OKS 37, HSS 84	10 years
Emerson et al. (2016) [17]	AKSS-O 93, AKSS-F 78	8 years
Faour Martin et al. (2013) [18]	AKSS-O 90.2 (SD 7.82), AKSS-F 88.6 (SD 17.8)	10 years
Foran et al. (2013) [19]	39 knees HSS 85-100, 6 knees HSS 70-84 and 4 knees had HSS 60-69	10 years
Kim et al. (2015) [29]	AKSS-O 85.4 (range 58-100), AKSS-F 80.5(range 50-100)	10 years
Kristensen et al. (2013) [31]	n.r	n.r
Lim et al. (2018) [37]	n.r for overall cohort	n.r
Lisowiski et al. (2016) [38]	OKS 41.9(SD 6.4), KSS 81(SD 20.7)	11.7 years
Pandit et al. (2015) [51]	OKS 40 (SD 9), AKSS-O 80 (SD 15), AKSS-F 76 (SD 22), Tegner 2.7 (SD 1.3)	10 years
Price et al. (2011) [55]	n.r	n.r
Schlueter-Brust et al. (2014) [59] (cemented arm)	n.r	n.r
Song et al. (2016) [61]	n.r for overall cohort	n.r
Venkatesh et al. (2016) [64]	KSS Clinical 91.8 (range 51-100) KSS Functional 92 (range 55-100)	Most recent follow up
White et al. (2018) [65]	n.r	n.r
Winnock de Grave et al (2018) [68]	OKS 43.3 (range 7-48)	Most recent follow up
Yoshida et al. (2013) [69]	OKS 38.1 (SD 6.8)	10 years

Table 6. Patient reported outcomes reported for the whole cohort at approximately 10 years. AKSS-O (American knee society score - objective), AKSS-F – (American knee society score - functional), HSS (Hospital for special surgery knee score), KSS (Knee society score), OKS (Oxford Knee Score), WOMAC (Western Ontario and McMaster universities arthritis index).

APPENDIX

Database searches

MEDLINE search

1 Knee/ or exp Knee Joint/ or Osteoarthritis, Knee/
2 knee*.tw.
3 1 or 2
4 Knee Prosthesis/ or Arthroplasty, Replacement, Knee/
5 (knee* and (arthroplast* or implant* or replace* or prosthe* or endoprosthe*)).tw.
6 4 or 5
7 "Prostheses and Implants"/
8 3 and 7
9 6 or 8
10 Cementation/
11 Bone Cements/
12 exp Hydroxyapatites/
13 (cement* or uncement* or hydroxyapatite or durapatite or hybrid or porous* or coat* or press-fit* or fixation or implant*).tw.
14 10 or 11 or 12 or 13
15 9 and 14
16 15
17 limit 16 to english language
18 Osteoarthritis, Knee/
19 osteoarthr*.tw.
20 18 or 19
21 17 and 20

EMBASE search

1 knee/
2 knee*.tw.
3 1 or 2
4 exp knee arthroplasty/
5 exp knee prosthesis/
6 (knee* adj2 (arthroplast* or implant* or replace* or prosthe* or endoprosthe*)).tw.
7 4 or 5 or 6
8 exp implantation/
9 3 and 8
10 7 or 9
11 cementation/
12 hydroxyapatite/
13 (cement* or uncement* or hydroxyapatite or durapatite or hybrid or porous* or coat* or press-fit* or fixation or implant*).tw.
14 11 or 12 or 13
15 knee osteoarthritis/
16 (knee and osteoarthr*).ti,ab.
17 15 or 16
18 10 and 14 and 17
19 18
20 limit 19 to english language

CENTRAL search

1 MeSH descriptor: [Knee] explode all trees
2 MeSH descriptor: [Knee Joint] explode all trees
3 knee*
4 #1 OR #2 OR #3
5 MeSH descriptor: [Arthroplasty, Replacement, Knee] explode all trees
6 MeSH descriptor: [Knee Prosthesis] explode all trees
7 (knee* and (arthroplast* or implant* or replace* or prosthe* or endoprosthe*))
8 #5 OR #6 OR #7
9 MeSH descriptor: [Prostheses and Implants] explode all trees
10 #4 AND #9
11 #8 OR #10
12 MeSH descriptor: [Cementation] explode all trees
13 MeSH descriptor: [Bone Cements] explode all trees
14 MeSH descriptor: [Durapatite] explode all trees
15 (cement* or uncement* or hydroxyapatite or durapatite or hybrid or porous* or coat* or press-fit* or fixation or implant*)
16 #12 OR #13 OR #14 OR #15
17 osteoarthr*
18 #11 AND #16 AND #17

Additional tables

Study	No of knees	Mean follow up	Observed component years	No of revisions	Revision rate per 100 component years (CI)
Cementless UKRs					
Campi et al. (2018A) [11]	682	7	4774	19	0.40 (CI 0.24-0.62)
Mohammad et al. (2019) [41]	1000	5.1	5100	18	0.35 (CI 0.21-0.56)
Schlueter-Brust et al. (2014) [59] (cementless arm)	78	11.6	904.8	2	0.22 (CI 0.03-0.80)
Mobile bearing Cementless			**10779**	**39**	**0.36 (CI 0.26-0.50)**
Hall et al. (2013) [20]	85	10	850	7	0.82 (CI 0.33-1.69)
Lecuire et al. (2014) [34]	101	11	1111	11	0.99 (CI 0.50-1.76)
Fixed bearing Cementless			**1961**	**18**	**0.92 (CI 0.54-1.45)**
CEMENTLESS OVERALL			**12740**	**57**	**0.45 (CI 0.34-0.58)**
Cemented UKRs					
Alnachoukati et al. (2018) [3]	825	9.7	8002.5	93	1.16 (CI 0.94-1.42)
Aly et al. (2010) [4]	45	8.75	393.8	2	0.51 (CI 0.06-1.82)
Campi et al. (2018B) [12] (cemented arm)	522	8.3	4332.6	40	0.92 (CI 0.66-1.25)
Edmonson et al. (2015) [16]	364	5.5	2002	26	1.30 (CI 0.85-1.90)
Emerson et al. (2016) [17]	213	10	2130	20	0.94 (CI 0.57-1.45)
Faour Martin et al. (2013) [18]	511	10.38	5304.2	29	0.55 (CI 0.37-0.78)
Kim et al. (2015) [29]	180	10	1800	16	0.89 (CI 0.51-1.44)
Kristensen et al. (2013) [31]	695	4.6	3197	51	1.60 (CI 1.20-2.10)
Lisowiski et al. (2016) [38]	138	11.7	1614.6	11	0.68 (CI 0.34-1.22)
Pandit et al. (2015) [51]	1000	10.3	10300	52	0.50 (CI 0.38-0.66)
Schlueter-Brust et al. (2014) [59] (cemented arm)	152	10.2	1550.4	7	0.45 (CI 0.18-0.93)
White et al. (2018) [65]	554	6.6	3656.4	16	0.44 (CI 0.25-0.71)
Yoshida et al. (2013) [69]	1279	5.2	6650.8	25	0.38 (CI 0.24-0.55)
Mobile bearing cemented			**50934**	**388**	**0.76 (CI 0.69-0.84)**
Argenson et al. (2013) [6]	70	20	1400	19	1.36 (CI 0.82-2.11)
Foran et al. (2013) [19]	19	19	361	3	0.83 (CI 0.17-2.41)
Lim et al. (2018) [37]	279	10.5	2929.5	11	0.38 (CI 0.19-0.67)
Song et al. (2016) [61]	68	9	612	3	0.49 (CI 0.10-1.42)
Venkatesh et al. (2016) [64]	175	5.6	980	7	0.71 (CI 0.29-1.47)
Winnock de Grave et al. (2018) [68]	460	5.5	2530	11	0.43 (CI 0.22-0.78)
Fixed bearing cemented			**8813**	**54**	**0.61 (CI 0.46-0.80)**
Chattelard et al. (2013) [13] Mixture of mobile and fixed	559	5.17	2890	14	0.48 (CI 0.27-0.81)
CEMENTED OVERALL	**8108**		**62637**	**456**	**0.73 (CI 0.66-0.80)**

Table A1. The calculated revision rates per 100 component years for each for the included studies

Study	No of revisions	Details of revisions
Cementless studies		
Campi et al. (2018A) [11]	19	1 Pain, 2 tibial loosening, 5 lateral disease progression, 1 patellofemoral dx, 2 tibial plateau fractures, 1 tibial overhang/impingement, 7 bearing dislocation
Hall et al. (2013) [20]	7	4 aseptic loosening, 1 sepsis, 2 OA progression
Lecuire et al. (2014) [34]	11	1 knee rheumatoid degeneration, 1 OA in lateral compartment, 1 increased pain, 1 ACL rupture, 3 polyethelene fracture, 4 bearing exchange for wear
Mohammad et al. (2019) [41]	18	7 bearing dislocation, 4 disease progression, 2 pain, 2 debridement washout and bearing exchange for infection, 1 AVN, 1 femoral comp loosening, 1 tibial plateau fracture
Schlueter-Brust et al. (2014) [59] (cementless arm)	2	1 pain, 1 bearing dislocation
Cemented studies		
Alnachoukati et al. (2018) [3]	93	19 tibial loosening, 5 tibial and femoral loosening, 6 tibial collapse, 22 arthritis progression, 2 tibial overload, 1 loose body removal, 7 femoral loosening, 13 unknown, 5 bearing dislocation, 1 tibial fracture, 1 instability, 1 car accident, 1 infection, 3 pain, 1 RA, 3 chronic haemarthrosis, 2 polywear impingement
Aly et al. (2010) [4]	2	1 fracture of medial tibial plateau, 1 aseptic loosening
Argenson et al. (2013) [6]	19	9 OA progression, 2 aseptic loosening, 3 patellafemoral prosthesis because of OA progression, 5 polyethelene wear
Chattelard et al. (2013) [13]	14	5 loosening, 5 tibial component wear, 2 lateral OA, 2 infection
Edmonson et al. (2015) [16]	26	9 Lateral compartment OA 5 Combination of lateral and patellofemoral OA 6 Aseptic loosening 4 Dislocated bearing 2 Unexplained medial pain
Emerson et al. (2016) [17]	20	3 chronic haemarthrosis 2 loose femoral components 2 loose tibial components 9 progression of OA in lateral compartment 1 bearing dislocation 1 polyethelene wear 2 unknown
Faour Martin et al. (2013) [18]	29	15 infection 2 bearing exchange for dislocation 8 persistent pain 4 aseptic loosening tibial component
Foran et al. (2013) [19]	3	2 patellofemoral and lateral OA, 1 lateral OA
Kim et al. (2015) [29]	16	7 bearing dislocations 1 bearing wear and breakage 1 MCL rupture with bearing dislocation 3 Femoral component loosening 1 Femoral and tibial component loosening 1 Component loosening with bearing dislocation 1 Tibial condylar fracture 1 Infection
Kristensen et al. (2013) [31]	51	8 aseptic loosening of tibial component 1 aseptic loosening of femoral component 2 aseptic loosening of both components

		14 Progressive OA in lateral compartment 2 Progression of retropatellar OA 10 Pain without loosening 4 Deep infection 2 Periprosthetic fracture 2 Malposition 4 Instability 2 Other
Lim et al. (2018) [37]	11	2 aseptic loosening, 6 OA progression, 1 poly fracure, 1 poly wear and progressive arthritis, 1 medial condylar fracture
Lisowiski et al. (2016) [38]	11	4 pain 6 disease progression 1 bearing dislocation
Pandit et al. (2015) [51]	52	25 Progressive OA in lateral compartment 7 bearing dislocation 7 unexplained pain 1 unknown 6 infection 1 ACL injury 1 ANV lateral femoral condyle 1 Tibial malposition 1 aseptic loosening femur 1 aseptic loosening tibia 1 instability
Schlueter-Brust et al. (2014) [59] (cemented arm)	7	4 pain, 3 bearing dislocation
Song et al. (2016) [61]	3	1 tibial plateau fracture, 1 tibial plateau collapse, 1 pain
Venkatesh et al. (2016) [64]	7	4 unexplained pain, 2 aseptic loosening, 1 poly wear
White et al. (2018) [65]	16	6 progressive arthritis, 4 instability, 3 unexplained pain, 1 aseptic loosening of tibia, 1 infection, 1 periprosthetic fracture
Winnock de Grave et al. (2018) [68]	11	4 infection, 2 lateral pain and overload, 2 pain and patellar chondropathy, 2 lateral OA, 1 synovitis
Yoshida et al. (2013) [69]	25	1 bearing rotation, 2 periprosthetic fracture tibia, 9 bearing dislocation, 12 tibial subsidence of component, 1 progression lateral OA

Table A2. The revision indications for the included studies in the mechanisms of failure analysis

LIST OF ABBREVIATIONS

AKSS-O – American knee society score (Objective)

AKSS-F – American knee society score (Functional)

CENTRAL – Cochrane Central of Controlled Trials

CI – Confidence interval

HSS – Hospital for special surgery knee score

KSS – Knee society score

MINOR – Methodological index for evaluation of non-randomised studies

OKS – Oxford Knee Score

PA – Per annum

PROM – Patient reported outcome measure

PRIMSA – Preferred reporting items for systematic reviews and meta analyses

TKR – Total knee replacement

WOMAC – Western Ontario and McMaster universities arthritis index

UKR – Unicompartmental knee replacement

CONFLICT OF INTEREST

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Some of the authors have received or will receive benefits for personal or professional use from a commercial party related directly or indirectly to the subject of this article. In addition, benefits have been or will be directed to a research fund, foundation, educational institution, or other non-profit organisation with which one or more of the authors are associated.

AUTHOR'S CONTRIBUTION

HRM, GB, JAK, SM, AJ and DWM designed the study. HRM and GB collected and analysed the data with statistical support from AJ and DWM. HRM, GB, JAK, SM, AJ and DWM helped with data interpretation. HRM wrote the initial manuscript draft which was then revised appropriately by all authors prior to submission.

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